Analysis of Behavior of the Atmospheric Characteristics in Areas of Activity of Tropical Cyclones Humberto and Katrina with the Data of Satellite Microwave Radiometric and Direct Measurements

A.G. Grankov[1], A.A. Milshin[2], E.P. Novichikhin[3]

V.A. Kotelnikov Institute of Radioengineerig and Electronics, Russian Academy of Sciences
1, Vvedenskii Sq., Fryazino, Moscow Region, 141190, Russia
[1]agrankov@inbox.ru; [2]amilshin@list.ru; [3]epnov@mail.ru

***Abstract*-We analysed a reaction of the system "ocean-atmosphere" characteristics on the passing of the powerful tropical cyclone Katrina in August 2005 in the Florida Strait in area of the station SMKF1 (Sombrero Key) as well as a behaviour of the system in the period of time preceding to arising and developing the cyclone Humberto in September 2007 in the Mexico Gulf in area of the station 42019. It was shown with the data of station (buoy) meteorological and simultaneous satellite microwave radiometric measurements in these areas that such characteristics as the near-surface air temperature, humidity and pressure, the fluxes of sensible and latent heat and impulse at the ocean-atmosphere boundary as well as the atmosphere integral water vapour content and enthalpy react clearly to the cyclone Katrina passing and to beginning and progress of the cyclone Humberto. The technique of analysis of the atmosphere integral characteristics such as its total water vapour content and enthalpy was developed. It enables us to determine variations of the atmosphere temperature and humidity at various horizons during passing the cyclone Katrina the station SMKF1 and birth of the cyclone Humberto in area of the station 42019. It was shown that in both cases the effect of taking off the heat energy by cyclones from the atmosphere and the ocean surface takes a place. This effect results in strong disturbances of the temperature, humidity and pressure in the near-surface atmosphere and is accompanied by a sharp decrease of the atmosphere enthalpy and considerable increase of the vertical turbulent heat and moisture fluxes at the ocean surface.**

Keywords-Microwave Radiometry; Tropical Cyclones; System Ocean-Atmosphere; Atmosphere Integral Water Vapour Content; Surface Heat and Momentum Fluxes

I. INTRODUCTION

Analysis of behavior of the ocean and atmosphere characteristics in zones of activity of the tropical cyclones (TC) over various stages of their existence is the actual task. Especial interest is a study of the air temperature and humidity in the atmosphere at the stages of TC *arising* (*passing*) preceding their *appearance* at present ocean area as well as at the stage of *relaxation*, i.e. returning the system "ocean-atmosphere" (SOA) to its initial state.

These characteristics are formed first of all due to an influence of the horizontal heat and moisture transfer in the atmosphere over the oceans. In mid latitudes of the North Atlantic subjected to regular impact of cyclones [1, 2] this factor determines an intensity of variations of the SOA heat (thermodynamic) and thermal (passive microwave) characteristics and their interrelations [3, 4].

Till now we did no conduct researches of relations between natural microwave radiation (brightness temperature) and the atmosphere temperature and humidity at lower (tropical) latitudes. Initially, an accent was made on the North Atlantic energy active zones (the Gulf Stream, Newfoundland, and Norwegian-Greenland ones), which determine the weather conditions and climatic trends at the European territory and the European part of the Russia. These zones subjected to regular impact of mid latitude cyclones are characterized by a strong sensitivity of the SOA brightness temperature to the atmosphere temperature and humidity, what manifests itself most distinctly during passing the mid latitude cyclones in the area of the Gulf Stream and North Atlantic currents. Observed in this time variations of the near-surface atmosphere temperature and humidity amount to tens degrees of Celcius and millibars, respectively, and the brightness contrasts – tens degrees of Kelvin [4]. These values considerably exceed the threshold of sensitivity of the vessel and satellites sensors and let us to register such changes in the SOA reliably.

Here we present some results of study of the SOA reaction to passing the powerful TC Katrina in August 2005 in the Florida Strait in area of the buoy station SMKF1 (Sombrero Key) as well as the results of a behavior of the system in the time period preceding to beginning and development of the TC Humberto and its dying in the Gulf of Mexico in September 2007 at the point of the buoy station 42019. An analysis of synoptic variations of the following ocean and atmosphere characteristics in these time periods was fulfilled:

1. Temperature of the ocean surface, air temperature, humidity, pressure and wind speed in the near-surface 10-th meter layer in area of the stations SMKF1 and 42019.

2. Vertical turbulent heat of sensible, latent heat and impulse at the sea-air boundary calculated with the measurement data the stations SMKF1 and 42019.

3. Total (integral) atmospheric water vapor content and enthalpy calculated by integration of the air humidity and temperature within the height range 10–10000 meters.

The source of information on the earth-based data is the American center National Data Buoy Center NOAA (NDBC); as the source of satellite data the data of regular measurements from the microwave radiometers SSM/I (Special Sensor Microwave/Imager) of the meteorological satellite F-17 DMSP

and AMSR-E (Advanced Microwave Scanning Radiometer) of the satellite EOS Aqua are used. The technical characteristics of these radiometers are given in [5] and [6], respectively.

Spacious network of meteorological of the NOAA stations, in particular, the stations situated in Mexico Gulf and the equatorial zone of the Pacific Ocean provide measurements of the parameters of the ocean surface and near-surface atmosphere, exclusively. Meteorological means of observations from these stations are not able to get reports about vertical distribution of the air temperature and humidity in atmosphere. This problem can be solved with use of measurement data of the multichannel microwave radiometer SSMIS (Special Sensor Microwave Imager/Sounder) from satellites DMSP F-16 and F-17 [7]. In addition to function of the scanner this device is able to determine the atmosphere temperature and humidity at various heights. However, a periodicity of remote sensing these atmospheric characteristics (once per day and night) is poor for studying such fast processes as forming the tropical cyclones, which characteristics can be varied essentially during several hours.

We developed the method combining data of the buoy measurements of the atmospheric near-surface layer and the ocean surface parameters with passive microwave radiometric measurements from satellites, which bring information on the air temperature and humidity not only in the near-surface atmosphere but also in overlying atmospheric layers. This technique allows us to determine values of the atmosphere temperature and humidity at various horizons (the property of satellite passive microwave radiometric measurements) and hourly (the property of buoy meteorological measurements).

Further, the results of study conducted point by point (1-3) will be illuminated.

II. DYNAMICS OF PARAMETERS MEASURED FROM THE STATIONS SMKF1 AND 42019

A. *Station SMKF1 (TC Katrina)*

The station SMKF1 from the NDBC data arsenal is used as the reference point in the Florida Strait (24.38o N, 81.07o W) when analyzing an influence of the TC Katrina on the atmospheric parameters. The nearest distance between a trajectory of the TC Katrina and this station was ~120 km in the noon of 26 August 2005, by this moment the cyclone has passed about 800 km from the place of its arising in area of the Bahama Islands.

Fig. 1 presents variations of the air temperature ta and pressure P in the atmosphere near-surface layer in the 21 and 31 August 2005 recorded by sensors of the SMKF1 station as well as computed values of the near-surface air humidity (water vapor pressure) e. These results were obtained with the technique developed by Snopkov [8], who analyzed and systemized numerous data of spacious experimental researches of relation of the parameter e with the difference of the water and air temperatures in various zones of the World oceans—the NOAA buoy stations do not includes direct measurements of the air humidity. Fig. 1 illustrates the smoothed results from the SMKF1 buoy station measurements of the parameters t_a, P and calculated estimates of the parameter e. A smoothing is fulfilled with the standard means of the computer program ORIGIN adjacent averaging with the 3-hour interval of averaging of the hourly samples. Initial data level from the SMKF1 sensors was 240 hourly samples for each of the parameters t_a, e and P, characterizing the stage proceeding an appearance of the TC Katrina in an area of the station SMKF1 (21-24 August), the stage of its passing this area (25-29 August) and the stage of the SOA relaxation (30-31 August).

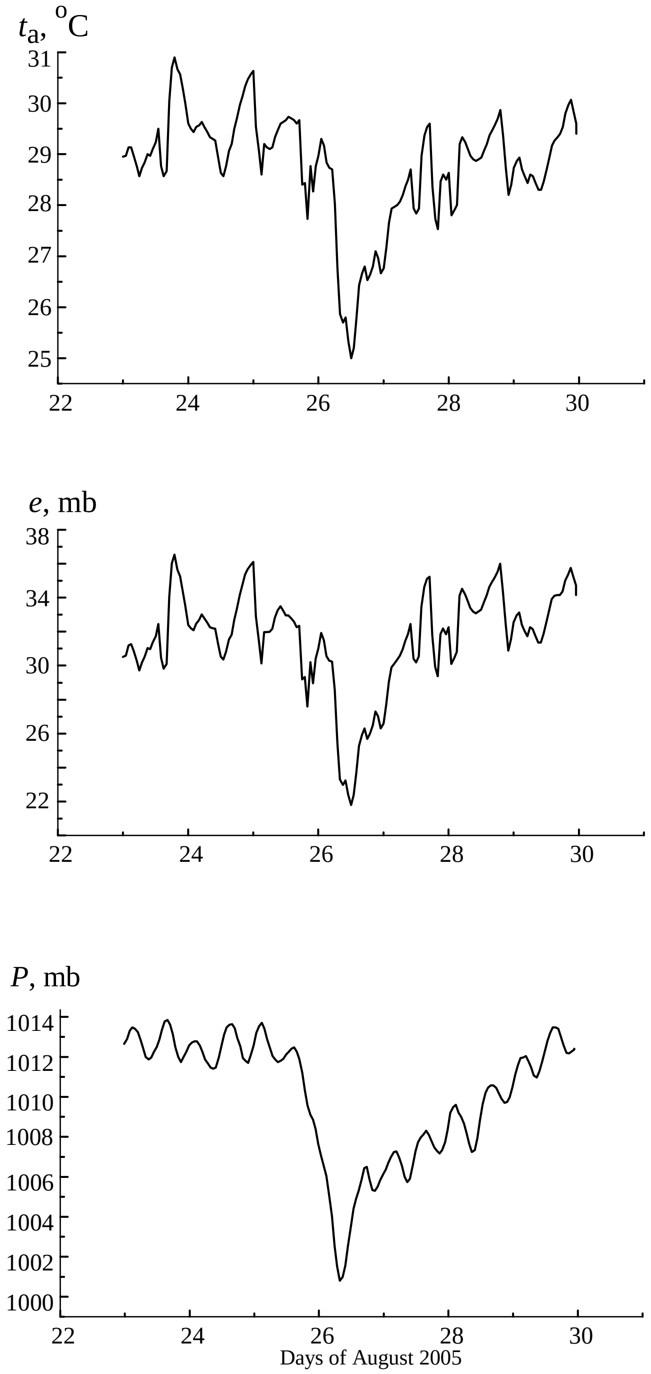


Fig. 1 Variations of the near-surface temperature t_a, humidity *e*, pressure *P* in the area of location of the station SMKF1 in the Florida Strait during passing the TC Katrina in August 2005

It is seen from the illustration that during passing the TC Katrina an area of the station SMKF1 one can observe significant variations of the near-surface air parameters with respect to their undisturbed (background) values observed before the coming and after the moving off of the cyclone. The contrasts of the air temperature, humidity pressure are about -6°C, -15 mb and -13 mb, respectively, reaction of the parameters ta, e and P to passing of the cyclone have a resonance character with duration of 3–4 days.

Results of the linear regression analysis show close interrelations between variations of the near-surface air temperature and humidity over all period observed (21-31 August), the coefficient of correlation of the parameters ta and e is 0.94.

Based on data of the buoy meteorological measurements and using the technique cited in [9] we computed values of the internal energy (enthalpy) of the near-surface atmosphere in the period from 21 to 31 August 2005. It was ascertained that when passing the point SMKF1 the TC Katrina collects the heat energy from the atmospheric near-surface layer, according to our estimates it is reducing roughly to 32500 J/m2 in this period.

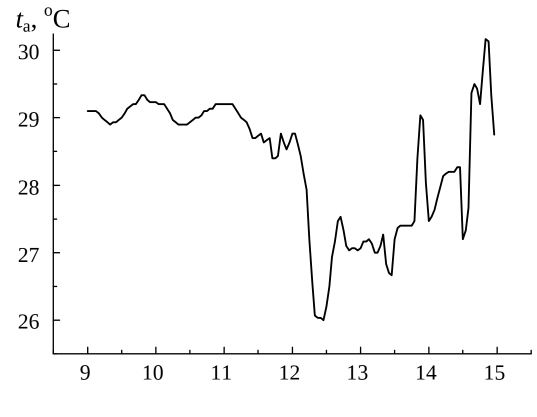
B. Station 42019 (TC Humberto)

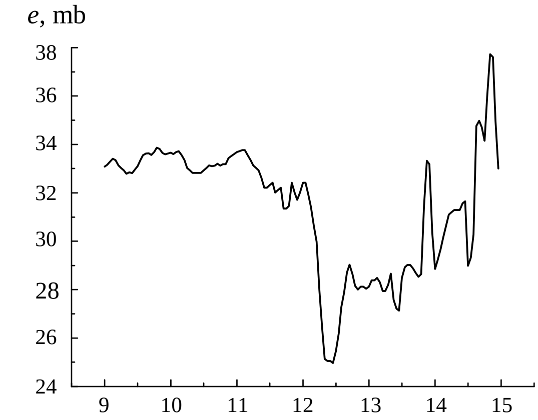
TC Humberto was born in the middle of September 2007 in the Gulf of Mexico. It was not such intensive as the cyclone Katrina, but it is attractive in our studies as the area's arising coincided with location of the buoy station 42019 situated in the point with coordinates 27.91^{o} N, 95.35^{o} W. This peculiarity let us to monitor parameters of the atmospheric near-surface layer (as well as parameters of overlying layers when using data of simultaneous passive microwave radiometric measurements) over various stages of forming the cyclone. According to the data of measurements from the station 42019 this point is characterized by a strong changeability of parameters of the atmospheric near-surface layer in the period of forming the TC Humberto: variations of the air temperature, humidity, and pressure and wind speed amount to 3^{o}C, 8 mb, 5 mb and 7 m/s, respectively.

Fig. 2 shows variations of the SOA parameters ta, and e between 9 and 14 September 2007 with adjacent 3-hour averaging of initial data (dataset of 144 hourly samples for each parameter) at the stage preceded to arising the TC Humberto (9-11 September), at the stage of its appearance (12 September), and at the stage of the SOA relaxation after leaving the cyclone the area of location of the station 42019 (13-14 September).

Variations of the near-surface air humidity in the period from 9 to 14 September practically repeat variations of the near-surface air temperature: the coefficient of their correlation is 0.97.

Also, we revealed that the near-surface air pressure is sharply declining at the stage of the cyclone arising (12 September), and wind speed is increasing with a lag of 5 hours, with account of this lag the coefficient of correlation between variations of the parameters P and V amounts to 0.91.





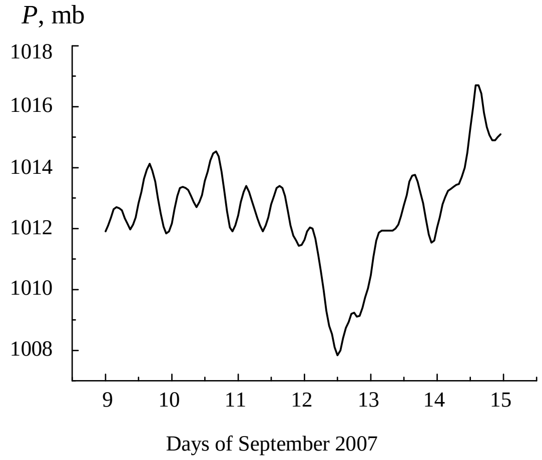


Fig. 2 Variations of the near-surface air temperature t_a, humidity e and pressure P from the measurement data of the station 42019 in the Gulf of Mexico during the starting of the TC Humberto in September 2007

We computed the atmospheric near-surface layer enthalpy between 9 and 14 September 2007 in the area of location of the station 42019, it follows from the results of computation that the enthalpy has been reduced on 125000 J/m2 during arising the TC Humberto.

C. Behaviour of the Ocean Surface Temperature in Areas of An Activity of the Tcs Katrina and Humberto

We carried out an analysis of variations of the ocean surface temperature during passing the TC Katrina past the station SMKF1 (22–31 August 2005) and during the period of forming and development of the TC Humberto (8–16 September 2007). These results are shown in Fig. 3. To emphasize the character of behavior of the ocean surface temperature, the data of buoy measurements are approximated with the standard means of the computer technique ORIGIN (Sigmoidal), which produces the stick-slip motion of original dependencies.

Fig. 3 demonstrates that the "jump" of the ocean surface temperature value in area of the station SMKF1 caused by passing the TC Katrina is in a few times more in comparison with this phenomena observed during beginning the TC Humberto.

It is interesting ad hoc that a transforming from one temperature regime to another one is occurring much fast in comparison with the case of the TC Katrina. In both cases one can observe the effect of taking off the heat energy by the atmosphere from the oceanic surface, as the "jump" of the ocean surface temperature is negative.

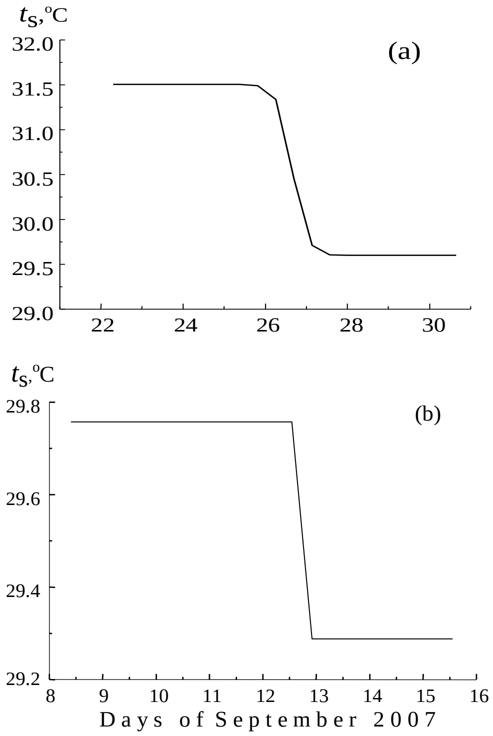


Fig. 3 Character of changes of the ocean surface temperature t_s: (a) an area of the station SMKF1 during passing the TC Katrina: (b) an area of the station 42019 in the period of forming the TC Humberto

III. DYNAMICS OF THE SURFACE FLUXES OF HEAT, AIR VAPOUR, AND IMPULSE

Resting upon the data of buoy measurements of the ocean surface temperature, the near-surface air humidity estimates and wind speed we computed the values of sensible q_h and latent q_e heat as well as the impulse q_v at the air-sea boundary using the well-known in dynamic meteorology formulas of the Global Aerodynamic Method), the so called Bulk Formulas were justified by Lappo in [2]. Due to this approach the values q_h and q_e are characterized with the following relationships:

$$q_h = c_p \rho c_t (t_{п} - t_a) V;$$

$$q_e = L \rho (0.622/P) c_e (e - e_o) V,$$

i.e., they become apparent through following parameters of the SOA: the air temperature t_a, pressure P, humidity e and wind speed V in the near-surface atmosphere, as well as through the ocean surface temperature t_s and proper for this maximal value of the air humidity e_o. As the constant of proportionality in these relations are served with the numbers of Schmidt c_t (heat exchange), Dalton c_e (moisture exchange), the specific heat of evaporation (L), the specific air heat under constant pressure (c_p), and its density (ρ).

Below are some results of computing the heat fluxes with reference to the stations SMKF1 and 42019 based on the buoy measurements in these areas of the Gulf of Mexico.

A. Station SMKF

Fig. 4 shows some results of computation of the heat fluxes (with 3-hour averaging). One can observe an influence of the passing of TC Katrina through the station SMKF1 seen in the form of appreciable reducing of the heat fluxes, about 20 W/m2 (from 30 to 10 W/m2 for the fluxes of sensible heat, and about 150 W/m2 from 350 to 200 W/m2 for the fluxes of latent heat). This result demonstrates an effect of smoothing the heat contrasts between the ocean surface and near-surface atmosphere due to an activity of the passing cyclone.

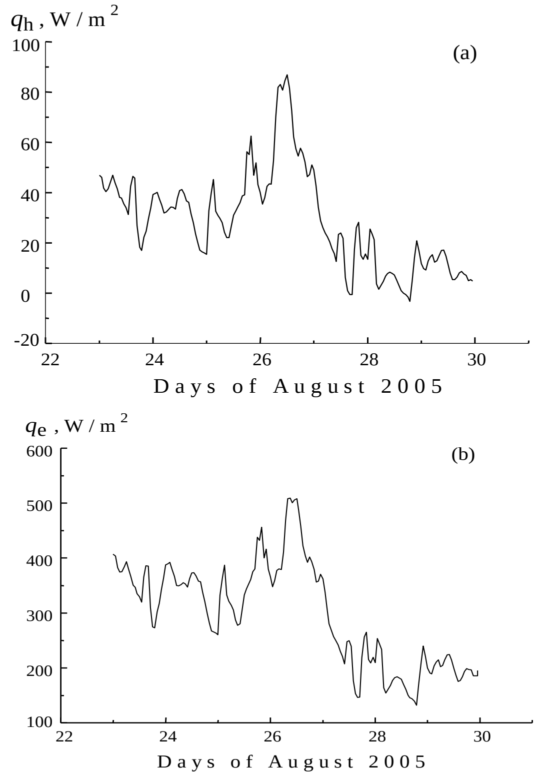


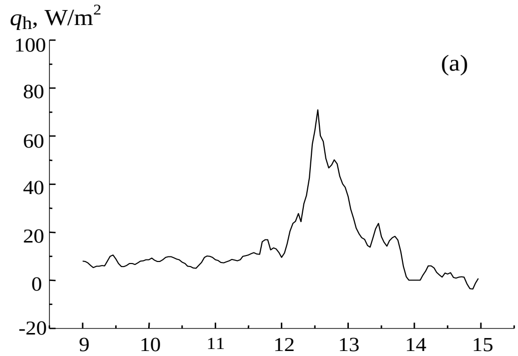
Fig. 4 Variations of sensible (a) and latent (b) heat at the ocean surface in area of the station SMKF1 location in the period of passing the TC Katrina in August 2005

The moment of passing of the cyclone past the station SMKF1 (the noon of 26 August) is accompanied by a positive increase of the parameters q_h and q_e, which amount to 80 and 500 W/m2, respectively, and coincide with the minimum of the parameters t_a, e and P in time (see Fig. 1).

B. Station 42019 (TC Humberto)

Fig. 5 shows results of computing the fluxes of sensible and latent heat and impulse (the 3-hour smoothing); one can observe here a sharp maximum peak of the values q_h, q_e and q_v simultaneously, which falls at the noon of 12 September 2007 that coincides with the data of ground observations of the TC Humberto development.

Average values of the heat and moisture fluxes at the stage preceding to the TC Humberto appearance (9-12 September) amount to 5 W/m2, 150 W/m2 and 0.05 N/m2, respectively, and their maximal values at the stage of its development in the noon of 12 September culminate to 75 W/m2, 530 W/m2 and 0.2 N/m2.



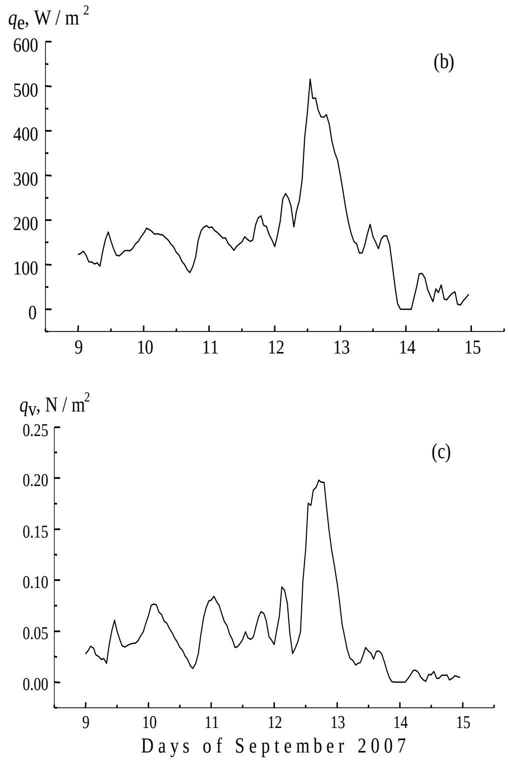
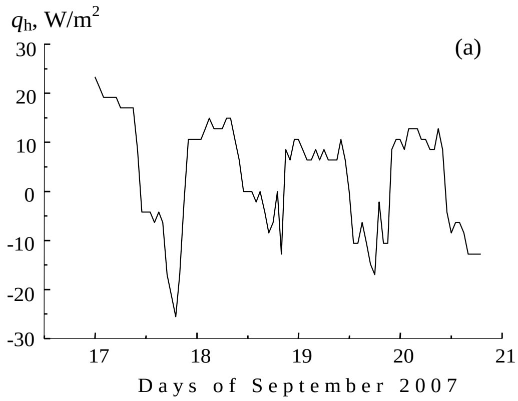


Fig. 5 Variations of fluxes of sensible (a), latent (b) heat and impulse (c) at the ocean surface in area of the station 42019 location in period of arising of the TC Humberto in September 2007

Notably, that maximal value of the total (sensible + latent) heat fluxes in area of the station 42019 (~ 600 W/m2) is close to the estimate cited by G.S. Golitsyn for tropical latitudes [10]. Also, this value is comparable with the total heat fluxes in the Newfoundland energy active zone of the North Atlantic, which is subjected regularly an influence of powerful mid latitude cyclones, which in compliance with the data of experiments NEWFOUEX-88 and ATLANTEX-90 reached to values of 800 W/m2 in March 1988 and April 1990 [11].

Fig. 6 demonstrates variations of the heat and moisture fluxes in the period 17-20 September at the stage of relaxation of the SOA parameters in area of the station 42019 after the arising of TC Humberto and leaving of this area.



It is seen from the illustration that average values of the parameters q_h and q_e in few times are less than their limit values observed in the noon 12 September. One interesting peculiarity is manifested itself: the oscillatory character of variations the heat and moisture fluxes in this time with the oscillation period closed to 24 hours, i.e. to the diurnal cycles. In addition, the sensible heat fluxes are alternating, that is the processes of heat transfer from the ocean surface to the atmosphere are alternated with the processes of heat transfer from the atmosphere to the ocean surface; this phenomenon was not observed in the period between 9-12 September preceding the appearance of the TC Humberto (see Fig. 5). This effect is similar to the effect of excitation of oscillations in high-Q resonant systems as the ringing circuits in radio-engineering, for example [12].

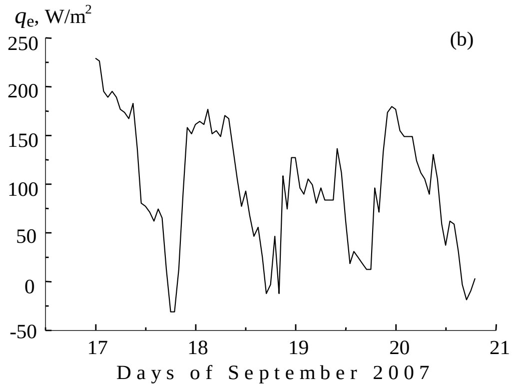


Fig. 6 Behavior of the sensible (a) and latent (b) heat fluxes at the ocean surface in area of the station 42019 location after the TC Humberto appearance

IV. DYNAMICS OF THE INTEGRAL WATER VAPOR CONTENT AND ENTHALPY OF THE ATMOSPHERE

A. *Technique of Determination of the Temperature and Humidity in the Atmospheric Upper Layers*

The sought dependences $t_a(h)$ and и $\rho(h)$ are found in the form of exponential functions $t_a(h) = t_a(0)\ \exp(-\kappa t\ h)$; $\rho(h) = \rho(0)\ \exp(-\kappa\rho\ h)$ providing a minimal root-mean-square error (discrepancy) between measured by the radiometers SSM/I и AMSR-E values of the SOA brightness temperatures and their simulated (model) estimates. The parameter ρ defines the air absolute humidity, which is used usually in computing the radiowave absorption in atmosphere and at the same time is uniquely bounded with the water vapor pressure e mostly used as the meteorological characteristic of the atmosphere. Values $t_a(0)$ and $\rho(0)$ are the conventional signs of the temperature and absolute humidity if the atmospheric near-surface is at 10-th meter layer.

As the microwave radiometers SSM/I and AMSR-E are the multi-channel systems, their measurement data are sufficient for determination of the coefficients κ_t and κ_ρ, required for retrieving the dependencies $t_a(h)$ and $\rho(h)$ over the ocean.

Whereas a frequency of the satellite microwave radiometric measurements is considerably less than a frequency of the buoy measurements, a linear interpolation of the SSM/I and AMSR-E data is used when computing the their discrepancy.

With the dependences of $t_a(h)$ and $\rho(h)$ the linear and integral absorption of microwave radiation in various atmospheric layers for all satellite microwave radiometric channels are computed.

From these data values of the SOA brightness temperature are computed using the-known plane-layer model of natural microwave radiation of the system [13]. According to this model the SOA brightness temperature is added from three components:

- brightness temperature of the up-going radiation of the ocean attenuated in the atmosphere, which depends on the water surface temperature, the near-surface wind speed, and the temperature and humidity characteristics of atmosphere;

- brightness temperature of the atmosphere up-going radiation, which is determined exclusively by the temperature and humidity of the atmosphere in different its layers;

- brightness temperature of the atmosphere down-going radiation reflected by the water surface, which depends both on the temperature and humidity of the atmosphere and on the temperature and wind state of the ocean surface.

The brightness temperature of up-going radiation and the coefficient of reflection of the ocean surface depend on the thermodynamic temperature of the water surface, its roughness and foaming intensity coupled with the near-surface wind speed; the computations were made with the model of microwave radiation based on systematization of theoretical and experimental data given in [13-15]. The brightness temperature of direct and reflected components of the atmosphere is determined by absorption of radiation in atmospheric water vapor and molecular oxygen, which depends on the air temperature, humidity and pressure and their vertical distribution [13]. The model relations are stable; they are recurred over various spatial and time scales in different oceanic areas [4, 11].

The value of discrepancy between simulated and measured estimates of the SOA brightness temperature is computed both with ascending as descending satellite orbits falling into cells 0.25^o x 0.25^o centralized about the stations SMKF1 and 42019 for the following spectral and polarization channels of the radiometers SSM/I and AMSR-E:

a) 37 GHz (0.81 cm), 19 GHz (1.58 cm), vertical and horizontal polarizations; 22.235 GHz (1.35 cm), vertical polarization (radiometer SSM/I);

b) 36.5 GHz (0.82 cm), 18.7 GHz (1.6 cm), 23.8 GHz (1.26 cm), vertical and horizontal polarization (radiometer AMSR-E).

When carrying out a joint analysis of the satellite and buoy data we did not take into account the channels 85 GHz (SSM/I) and 89 GHz (AMSR-E) as these results strongly depend on the precipitation intensity, which did not considered in computations of the SOA brightness temperatures. Also, we expected from our consideration the data of measurements in the channels 6.9 GHz (4.35 cm) and 10.65 GHz (2.82 cm) of the radiometer AMSR-E, bringing information about characteristics of the underlying surface mainly; in this stage of the study the behavior of the SOA meteorological parameters during the cyclonic activity of the atmosphere is emphasized.

The techniques developed let us compute approximately values of the temperature and humidity of the atmosphere at various horizons for estimating its integral characteristics such as the total water vapor content and enthalpy (heat content), for example. It seems that namely the atmosphere integral characteristics will be informative for an analysis of the SOA dynamics in zones of activity of the tropical cyclones in spite of the fact that the real profiles of the air temperature and humidity can be appreciably differ from the exponential ones.

Resting upon the buoy data on the air humidity in the near-surface layer and the computed estimates of this parameter in overlying atmosphere layers the integral water vapor content of the atmosphere (IVA) Q in the layer 10–10000 m was computed. A comparison of the results of computing the parameter Q with its satellite estimates derived with the radiometer SSM/I in area the station SMKF1 and the radiometer AMSR-E in area of the station 42019 was made.

Besides, the calculation estimates of the atmosphere enthalpy for various its layers were obtained in areas of activity of the TCs Katrina and Humberto.

B. Dynamics of the Atmosphere Integral Water Vapor Content in Area of the Station SMKF1

Fig. 7 compares the estimates of the IVA variations in area of the station SMKF1 during the period 1–30 August 2005 computed by a layerwise integrating of the air humidity at various heights with the satellite estimates of the parameter Q derived with the measurement data from the radiometer SSM/I using the known technique [16].

One can observe the appreciable IVA variations in a given area of the Florida Strait, which are accompanied with some local falls of the Q value; one of them coincides (in the noon 25 August the 2005 – the time of passing TC Humberto the station SMKF1) with the minimums of the near-surface air temperature, humidity, and pressure and with the maximums of the of sensible and latent heat fluxes (see Fig. 4).

A difference between the absolute values of the computed and satellite estimates of the parameter Q can be explained by the fact that when modeling the SOA brightness temperature we did not keep in mind its increase caused by the cloudiness and precipitation, which are registered by the satellite radiometer SSM/I. An irregularity of remote sensing an area of the SMKF1 station and availability of noticeable gaps in the satellite measurements also take an important part. That dictates the necessity to operate not only with the factual data of satellite measurements from the radiometer SSM/I but also with the results of their interpolation. Though, one can mark a good compliance of relative changes (variations) of the both estimates); this is essential for validation of the developed technique of determination of the air temperature and humidity and especially, of their changeability at various horizons of the atmosphere under arising (passing) the tropical cyclones.

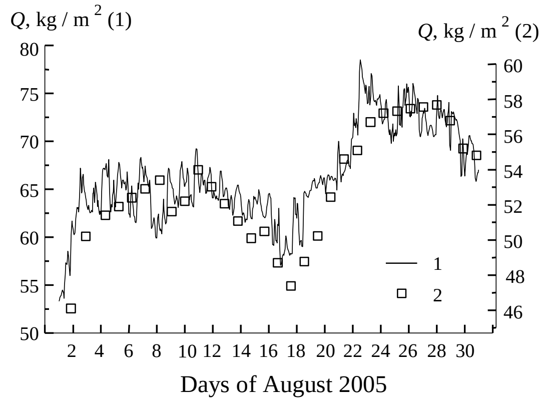


Fig. 7 Comparing of the estimates of the atmosphere integral water vapor content Q in area of the station SMKF1: 1- data of computing for the layer 10–10000 m; 2- data of measurements of the radiometer SSM/I

C. Dynamics of the Atmosphere Integral Water Vapor Content in Area of the Station 42019

We derived the IVA estimates in area of the station 42019 in the period 6–15 September including the stages of arising the TC Humberto and its appearance and obtained the satellite

estimates of the parameter Q with the data of measurements from the radiometer AMSR-E (see Fig. 8).

It is seen from the illustration that the arising TC Humberto is accompanied by increase of the value of Q (in the noon of 12 September); one can observe that maximum of Q (in the noon 12 September) happens together with minimums of the near-surface air temperature, humidity and pressure, with maximum of the wind speed (see Fig. 2) and maximums of fluxes of sensible, latent heat and impulse (see Fig. 5). To the peak of values of Q on 12 September precedes the fragment (7-9 September) with increased water vapor content of the atmosphere.

Fig. 9 compares the satellite and simulated estimates of the parameter Q after leaving by the TC Humberto an area of the station 42019 for the time interval 13–20 September. It follows from the illustration that it occurs reducing the IVA value in this period, which has the oscillatory character similarly to the case of the surface heat and moisture fluxes (see Fig. 6).

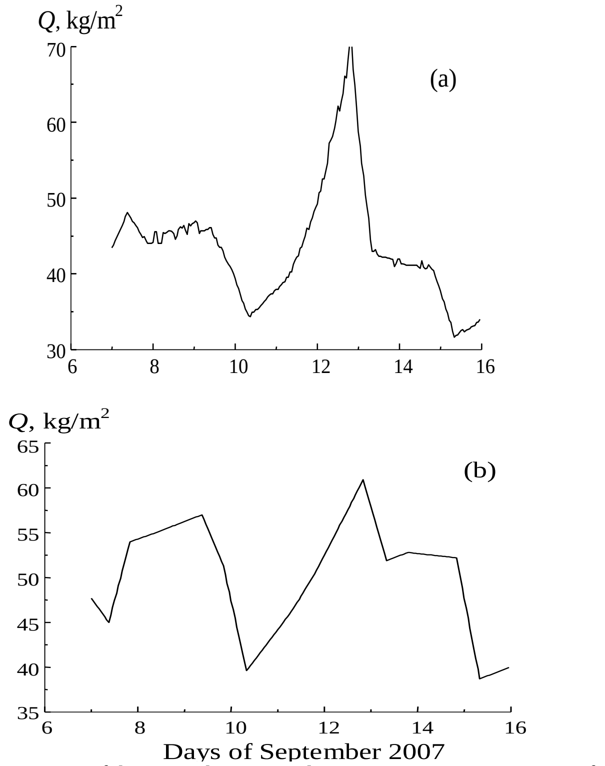


Fig. 8 Estimates of the atmosphere integral water vapor content Q in area of the station 42019: (a)- data of computation for the atmosphere layer 10-10000 m; (b)- data of measurements from the radiometer AMSR-E of the satellite EOS Aqua

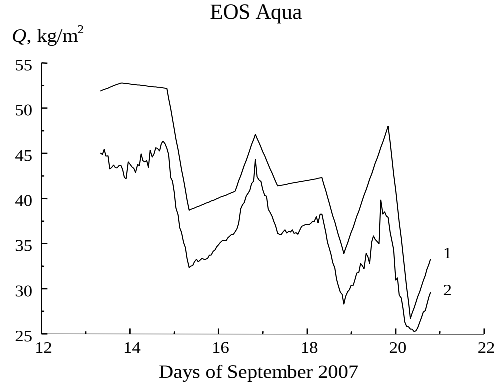


Fig. 9 Compare of satellite (1) and simulated (2) estimates of the atmosphere integral water vapor content Q after leaving by the TC Humberto an area of the station 42019

D. Dynamics of the Atmosphere Enthalpy in Area of the Stations SMKF1 and 42019

We computed variations of the enthalpy (heat content) of various atmospheric layers in areas of the stations SMKF1 and 42019 in periods of activity of the TCs Katrina and Humberto. Fig. 10 demonstrates some results of computation of the enthalpy J for the layer 10-10000 m.

The illustration shows that during passing the TC Katrina the station SMKF1 and arising of the TC Humberto in area of the station 42019 we can observe a sharp reduction of the J10000 value. This reduction has the resonant type and is accompanied by a strong increase of the vertical turbulent heat and moisture fluxes at ocean-atmosphere boundary (see Figs. 5). Thus, it is occurred a taking of the atmosphere heat energy by cyclones in these areas, just like this effect is occurred for the mid latitude cyclones in the Newfoundland energy active zone of the North Atlantic in the experiment ATLANTEX-90 as shown in [4].

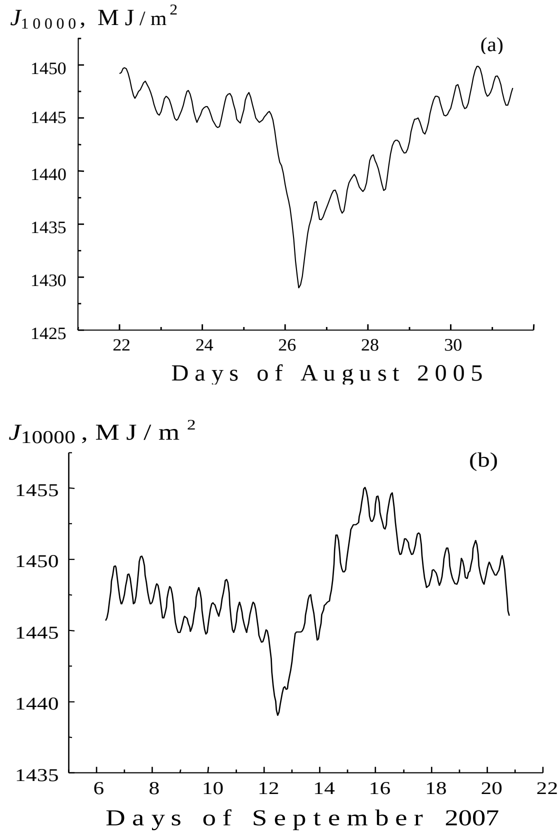


Fig. 10 Variations of the atmospheric enthalpy J10000 during passing the TC Katrina the station SMKF1 (a) and arising the TC Humberto in area of the station 42019 (b)

E. About Regularity of Satellite Microwave Radiometric Measurements

A frequency (periodicity) of satellite microwave radiometric measurements is an order less than a frequency of the buoy meteorological measurements, therefore the question appears: is it sufficient to reflect the rapid-change processes in the SOA concerned with passing or arising of tropical cyclones. To answer this question we fulfilled an analysis of a regularity of measurements from the F-17 SSM/I radiometer in area of the station SMKF1 and the EOS-Aqua AMSR-E radiometer in area of the station 42019 at different stages of the TCs Katrina and Humberto activity (Fig. 11).

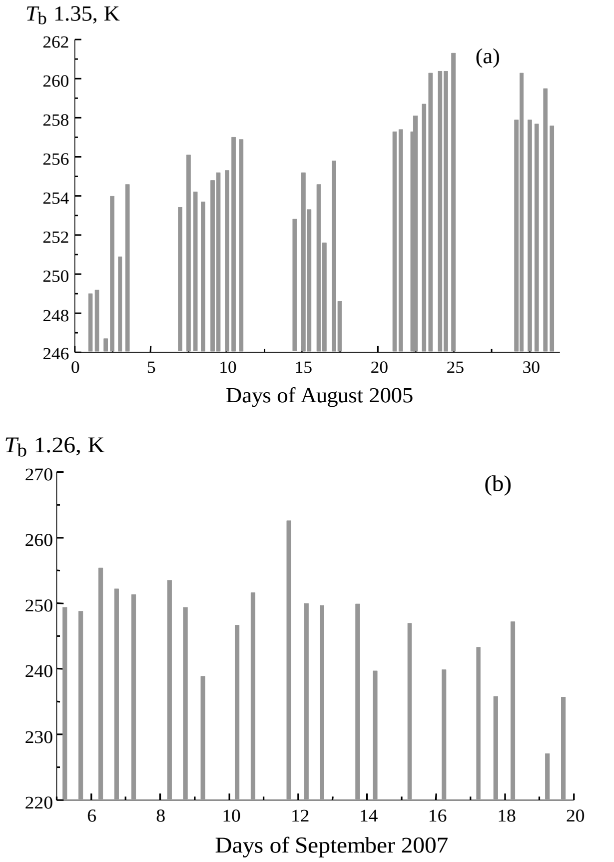


Fig. 11 Regularity of measurements from the satellite DMSP F-17 in area of the station SMKF1 in August 2005 (a) and the satellite EOS Aqua in area of the station 42019 in September 2007 (b)

Fig. 11a shows all assembly of samples of the brightness temperatures measured by the SSM/I radiometer at the wavelength 1.35 cm (at the vertical polarization) on ascending and descending orbits of the satellite F-17 between 1 and 31 in the period from 1 to 30 August 2005. Let`s note that the number and the time place of the samples for the rest spectral and polarization channels of the radiometer exactly correspond to these shown in the figure. It follows from the illustration that the number of samples in August amounted was equal to 37 (relatively, the number of the buoy measurements in this period amounted to 744). Noticeable gaps in the satellite measurements are observed: four gaps with duration 80–90 hours, the last of them happening to be just in the time of passing the TC Katrina through the station SMKF1 (Fig. 11a).

A situation with a periodicity of microwave radiometric measurements the satellite EOS Aqua is more favorable for carrying out a joint analysis of the remote sensed and direct measurements in area of the station 42019; the number of the satellite samples between 5 and 19 September 2007 reached was equal to 22, and the number of the buoy measurements amounted to 360 (Fig. 11b). Evident gaps in that case are absent, and the time interval between satellite samples does not exceed 22 hours.

V. CONCLUSIONS

The dynamics of different characteristics of the atmosphere in periods of activity of the tropical cyclones Katrina (August 2005) and Humberto (September 2007) were studied. The study was based on coupling the data of the buoy meteorological measurements with the data of simultaneous measurements from the DMSP SSM/I radiometer (in area of the NOAA station SMKF1) and the EOS-Aqua AMSR-E radiometer (in area of the station 42019).

The technique of analysis of the atmosphere integral characteristics, such as its total water vapor content and enthalpy was developed. It enables to determine variations of the atmosphere temperature and humidity at its various horizons during the TC Katrina passing the station SMKF1 and arising at the TC Humberto in area of the station 42019.

It is shown that in both cases the effect of taking off heat energy by cyclones from the atmosphere and the ocean surface takes place. This effect results in strong disturbances of the temperature, humidity and pressure in the near-surface atmosphere and is accompanied by a sharp decrease of the atmosphere enthalpy and considerable increase of the vertical turbulent heat and moisture fluxes at the ocean surface.

The following features of the results of an analysis of the SOA parameters dynamics during the process of arising at the TC Humberto can be noted:

1) oscillating nature of behavior of the sensible and latent heat fluxes as well as the atmosphere integral water vapor after leaving by the cyclone the area of its arising, i.e. at the stage of the SOA relaxation;

2) availability of anomalies in behavior of the atmosphere integral water vapor 4-5 days before an appearance of the TC Humberto that foods the thoughts: whether become these anomalies as the tropical hurricanes signs?

This guess is required in further examination with use of the data of observing the processes of arising of other tropical hurricanes in various oceanic areas in various years and seasons taking into account of an effect of the atmospheric horizontal circulation.

A good agreement between simulated and satellite estimates of the variations of the atmosphere water vapor content in areas of the stations SMKF1 and 42019 indicates that the adopted exponential model of vertical distribution of the air temperature and humidity provides useful information about dynamics of this integral characteristic of the atmosphere state, which is important for studying the influence of transient and developing tropical cyclones on the state of the “ocean-atmosphere” system. Unlike the satellites estimates characterizing the total water vapour content of the atmosphere in the layer 10–10000 m, the technique developed enables to determine its value in other atmospheric layers.

ACKNOWLEDGMENTS

These investigations were conducted in a frame of the project on elaboration of technologies for diagnosis of tropical hurricanes beginning in oceans. The project was maintained by the International Scientific and Technological Center (ISTC) in 2008-2011, grant No. 3827. We are grateful to Drs Vladimir Krapivin, Anatlii Shutko, and Sergey Golovachev (V.A. Kotelnikov Institute of Radioengineering and Electronics RAS) for collaboration and useful discussions.

REFERENCES

[1] S.K. Gulev, A.V. Kolinko, and S.S. Lappo, *Synoptic interaction between the ocean and atmosphere in middle latitudes*. St. Petersburg, Russia: Gidrometeoizdat, 1994 (in Russian).

[2] S.S. Lappo, S.K. Gulev, and A.E. Rozhdestvenskii, *Large-scale heat interaction in the ocean-atmosphere system and energy-active zones in the world ocean*. Leningrad, USSR: Gidrometeoizdat: 1990 (in Russian).

[3] A.G. Grankov and A.A. Mil`shin. *Intercorrelation between natural microwave radiation of the ocean-atmosphere system and its boundary heat and dynamic interaction*. Moscow, Russia: Fizmatlit (Nauka), 2004 (in Russian).

[4] A.G. Grankov and A.A. Mil`shin, *Microwave radiation of the ocean-atmosphere: boundary heat and dynamic interaction.* Berlin, Germany: Springer-Verlag, 2010.

[5] P.H. Hollinger, J.L. Peirce, and G.A. Poe, "SSM/I instrument evaluation", *IEEE Trans. Geosci. Rem. Sensing*.", vol. 28, pp. 781-790, 1990.

[6] T. Kawanishi, T. Sezai, Y. Ito, K. Imaoka, T. Takeshima, Y. Ishido, A. Shibata, M. Miura, H. Inahata, R.W. Spenser. The advanced microwave scanning radiometer for the Earth Observing System (AMSR-E), NASDA's contribution to the EOS for global energy and water cycle studies. "*IEEE Trans. Geosci. Remote Sens.*", no. 48, pp. 173-183, 2003.

http://www.ndbc.noaa.gov/

[7] D. Kunkee, D. Boucher, G. Poe and S. Swadley, "Evaluation of the Defense Meteorological Satellite Program (DMSP) Special Microwave Imager Sounder (SSMIS)", in *Proc. IGARSS`06*, pp. 101-104, 2006.

[8] V.G. Snopkov, "Computation of the near surface air over the sea from the air-sea temperature differences", *Meteorologija i Gidrologya*, no. 2, pp. 109-111, 1980 (in Russian).

[9] A.X. Xrgian. *Physics of the atmosphere*, vol.1. Leningrad, USSR, Gidrometeoizdat, 1978 (in Russian).

[10] G.S. Golytsyn, "Polar lows and tropical hurricanes: their energy and sizes and a quantitative criterion for their generation", *Izvestija, Atmosp. Oceanic Phys.*, vol. 44, no. 5, pp. 579-590, 2008 (in Russian).

[11] N.A. Armand, A.G. Grankov, A.A. Mil`shin, S.S. Lappo, and S.K. Gulev, "Use of the data of simultaneous satellite microwave radiometric and ship-borne measurements for the study of air-sea interaction in the North Atlantic", *Oceanology*, vol. 44, no. 1, pp. 44-54, 2004.

[12] A.A. Kharkevich, *Bases of the radioengineering* (3-th edition). Moscow, Russia: Fizmatlit, 2007 (in Russian).

[13] A.E. Basharinov, A.S. Gurvich,. and S.T. Egorov S.T. *Radio emission of the planet Earth*. Moscow, USSR: Fizmatlit (Nauka), 1974 (in Russian).

[14] I.V. Cherny and V. Yu. Raizer. *Passive microwave remote sensing of oceans*. Wiley UK, 1998.

[15] A.M. Shutko, *Microwave radiometry of water surface and soils.* Moscow, USSR: Fizmatlit (Nauka), 1986 (in Russian).

[16] J.C. Alishouse, S.A. Snyder, J. Vongsatorn, and R.R. Ferrado. Determination of oceanic total precipitate water from the SSM/I."J. Geophys. Res" , vol. 28, no. 5, pp. 811-816, 1990.

Alexander G. Grankov received the Dr. Sci. degree from Moscow Power Engineering Institute (1987) and the Ph. D. degree in remote sensing of the Earth from the Institute of Radioengineering and Electronics of Russian Academy of Sciences (IRE RAS), Fryazino department (2002).

His research interests include interpretation of passive microwave radiometric measurements from satellite and aircrafts.

Evgeny P. Novichikhin received the M.S. degree in mathematics from Moscow State University (1972) and D. Sci. degree in biophysics from Moscow State University (1985).

Since 1972 he is with the Institute of Radioengineering and Electronics of Russian Academy of Sciences (IRE RAS), Fryazino Department, Moscow Region. His research interests include remote sensing and image processing.

Alexander A. Milshin obtained M.Sc from Moscow Power Engineering Institute (1978). His research interests include Remote sensing of the ocean and land covers, modeling and processing the data of microwave radiometric measurements from satellites and aircrafts. His special research interests are in study of potential of the L-band satellite passive microwave radiometry.

He is working as Senior Scientist in Kotel'nikov Institute of Radio Engineering and Electronics of Russian academy of sciences (1978) and Federal State Unitary Enterprise "Research & Production Corporation" ISTOK" (2000). He was Head of Division Institute of Geoinformatics, Ltd., Fryazino (1991-1995). He has published 3 books, more than 60 peer-reviewed publications and 140 presentations at national/international conferences. He is member of Popov's Radio engineering Society.